TITLE OF THE INVENTION

DISTORTION MEASUREMENT METHOD AND EXPOSURE APPARATUS

FIELD OF THE INVENTION

The present invention relates to a distortion measurement technique for manufacturing a device such as a semiconductor element, image sensing element (CCD or the like), liquid crystal display element, thin-film magnetic head, or the like.

BACKGROUND OF THE INVENTION

As disclosed in Japanese Patent No. 3,959,190, at least five methods are well known as a method of measuring a distortion (distortion component generated when a mask image is transferred onto a wafer) in the projection optical system of an exposure apparatus.

Of these methods, two methods disclosed in Japanese Patent No. 3,959,190 and Japanese Patent Publication No. 63-38697 are proposed as a distortion measurement method using overlay of a main scale mark and vernier scale mark.

(1) Method Disclosed in Japanese Patent Publication No. 63-38697

According to the method disclosed in this reference, a main scale mark 2 and vernier scale marks 1 which are formed on a test reticle as shown in Fig. 8A are transferred onto the resist layer of a

photosensitive substrate, as shown in Fig. 8B. The misalignment amount of the overlay mark after developing (distance from the barycenter of the main scale mark to that of the vernier scale mark) is measured. In inspection, the vernier scale marks 1 on the entire reticle surface are transferred onto the photosensitive substrate. Exposure is repeated by sequentially moving the photosensitive substrate such that the main scale mark 2 overlaps the previously transferred vernier scale marks 1 at a plurality of points.

The photosensitive substrate is moved by a precision moving stage having a high-precision critical dimension measurement device such as a laser interferometer. The moving amount is uniquely determined in correspondence with the designed intervals between the central point and a plurality of points on the reticle. In exposure to the main scale mark 2, the moving stage is moved by a distance corresponding to the interval. The photosensitive substrate which has already been exposed to the vernier scale mark is exposed to the main scale mark 2. An overlay mark 13 as a result of overlaying the main scale mark and vernier scale marks is formed on the entire exposure region of the developed photosensitive substrate, as shown in Fig. 9. These marks are read visually (via a microscope), obtaining an overlay error

amount at the target point. If the moving stage is accurately fed, the measurement value (overlay error amount) corresponds to a distortion amount at the target point.

(2) Method Disclosed in Japanese Patent No. 3,959,190

The method disclosed in this reference uses a reticle having main scale marks 14a and 15a, and vernier scale marks 14b and 15b which are arranged at predetermined small intervals in two directions perpendicular to each other, as shown in Figs. 10A and 10B. Distortion difference amounts in the two directions perpendicular to each other are transferred onto overlay marks at respective positions. A distortion is derived from the cumulative sum of misalignment amounts obtained by measurement using a microscope.

More specifically, a pattern on the entire surface of a test reticle is transferred onto a substrate by exposure. The substrate holding stage is moved by Δy in the first direction and Δx in the second direction such that the main scale marks 14a and 15a are moved adjacent to the previously transferred vernier scale marks 14b and 15b. Immediately after movement, an overlay mark as shown in Figs. 11A and 11B is formed by exposure. The misalignment amounts of the two overlay marks formed in this manner exhibit distortion changes in the respective directions. The

change amount is divided by the moving amount, obtaining a distortion inclination. The inclination is multiplied by each mark interval to obtain a cumulative sum. The distortion of the entire exposure region can therefore be calculated.

However, the conventional distortion measurement methods described above suffer the following problems.

In measurement method (1), the feed error of the moving stage is added to the misalignment amount of the overlay mark, resulting in poor measurement precision. If the feed error of the moving stage varies irregularly, the precision can be increased by calculating the average value by a plurality of measurement operations. However, a plurality of measurement operations take a long time, increasing the inspection cost. In the presence of a regular feed error of the moving stage, the precision cannot be increased by a plurality of measurement operations.

Measurement method (2) executes only feed of the moving stage in two directions perpendicular to each other and at least two exposure operations, and the measurement time is short. However, the misalignment amount of the overlay mark which reflects a distortion change is divided by the distance between a corresponding main scale mark and vernier scale mark, obtaining a distortion inclination amount. The distortion inclination amount is multiplied by the

distortion measurement interval, obtaining a change amount from an adjacent measurement point. In general, the distance from an adjacent measurement point is longer than the distance between a corresponding main scale mark and vernier scale mark. A small measurement error upon measuring a misalignment amount by a microscope increases by the distance ratio. The increased error is undesirably regarded as the cumulative sum and contained in the distortion.

In the above situation, demands have arisen for higher-precision distortion measurement.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a distortion measurement method comprising: a first formation step of repeating, m x n times, shot exposure of arranging first marks on a photosensitive substrate via a reticle and a projection optical system in M rows and N columns at a predetermined column interval and a predetermined row interval, thereby forming first marks in M x m rows and N x n columns on the photosensitive substrate, M and m being natural numbers which are relatively prime, N and n being natural numbers which are relatively prime, and M > m and N > n; a second formation step of repeating, M x N times, shot exposure of arranging second marks on the photosensitive substrate via the reticle in m rows and

n columns at the predetermined column interval and the predetermined row interval, thereby forming second marks in M x m rows and N x n columns on the photosensitive substrate, the first and second marks formed in the first and second formation steps forming M x m x N x n overlay marks; a measurement step of measuring misalignment amounts of the first and second marks for each of the M x m x N x n overlay marks; and a calculation step of calculating a distortion amount on the basis of the misalignment amounts measured in the measurement step.

According to another aspect of the invention, there is provided a method comprising: a first exposure step of exposing each of first shot regions on a substrate to a plurality of first marks aligned at a predetermined interval via a master and a projection optical system; a second exposure step of exposing each of second shot regions on the substrate to a plurality of second marks aligned at the predetermined interval via the master and the projection optical system, the first and second shot regions being so arranged as to make positions of a plurality of transferred first and second marks on the substrate correspond to each other, the plurality of transferred first and second marks being formed due to said first and second exposure step respectively, and number of the transferred first marks in the first shot region being larger than number of

the transferred second marks in the second shot region; and a calculation step of calculating a distortion amount of the projection optical system based on a positional difference measured for the transferred first and second marks which correspond to each other.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Figs. 1A and 1B are views showing reticle-shielded states in the first and second layers in distortion measurement processing according to an embodiment;

Fig. 2 is a view showing a mark that is transferred by the first layer onto a substrate in distortion measurement processing according to the embodiment;

Figs. 3A and 3B are views showing an overlay mark

which is formed on a substrate up to the middle of the second layer in distortion measurement processing according to the embodiment;

Figs. 4A and 4B are views showing a definition example of a distortion within a shot;

Fig. 5 is a view showing a definition example of the alignment error of each shot transferred by the first layer;

Fig. 6 is a view showing a definition example of the relative position error of a main scale mark transferred by the second layer;

Fig. 7 is a view showing a definition example of the alignment error of each shot transferred by the second layer;

Figs. 8A and 8B are views showing reticle-shielded states in the first and second layers in the prior art;

Fig. 9 is a view for explaining a conventional distortion measurement method;

Figs. 10A and 10B are views for explaining the conventional distortion measurement method;

Figs. 11A and 11B are views for explaining the conventional distortion measurement method;

Fig. 12 is a block diagram for explaining an exposure system which realizes the distortion measurement method of the embodiment;

Fig. 13 is a flow chart for explaining the

operation of an exposure control apparatus which executes the distortion measurement method of the embodiment;

Fig. 14 is a flow chart showing the manufacturing flow of a microdevice; and

Fig. 15 is a flow chart showing the detailed flow of the wafer process in Fig. 14.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred embodiment of the present invention will now be described in detail in accordance with the accompanying drawings.

The embodiment realizes higher-precision distortion. The outline of the measurement method will be explained with reference to Figs. 1A to 3B.

A reticle has, on the entire exposure target surface, vernier scale marks drawn in m_1 rows and n_1 columns at a predetermined interval in the first direction (to be referred to as a column direction hereinafter) and the second direction (to be referred to as a row direction hereinafter) perpendicular to the first direction. In Fig. 1A, vernier scale marks 1 in nine rows and seven columns are arranged at an interval p_x in the row direction and an interval p_y in the column direction. The reticle also has, on part of the exposure target surface, main scale marks 2 drawn in at least m_2 rows and n_2 columns at the same intervals (p_x

and p_y) as those of the vernier scale marks. In this case, $m_1 > m_2$ and $n_1 > n_2$, and m_1 and m_2 are natural numbers which are relatively prime whereas n_1 and n_2 are natural numbers which are relatively prime. This example adopts two rows and two columns (that is, $m_2 = n_2 = 2$). Fig. 1A shows main scale marks 2 in nine rows and seven columns, similar to the vernier scale mark. The reticle is shielded by a light-shielding plate so as to transfer 2 x 2 vernier scale marks, as shown in Fig. 1B, as will be described later.

In the first step, the m_1 x n_1 vernier scale marks 1 arranged on the entire reticle surface as shown in Fig. 1A are transferred onto a substrate by one exposure using an exposure apparatus subjected to distortion inspection (first layer exposure processing). The moving stage of the exposure apparatus is moved by a step in the column direction, and the first layer exposure processing is so done as to successively align the vernier scale marks 1 in a region adjacent in the column direction. This operation is repeated m_2 times. Also in the row direction, step movement and transfer are so repeated as to successively align the vernier scale marks in a region adjacent in the row direction. This operation is repeated n_2 times in the row direction. That is, step movement by a p_x x n_1 distance in the row direction, or step movement by a p_y x m_1 distance in

the column direction, and the first layer exposure processing are repeated m_2 x n_2 times, transferring m_2 x n_2 shots 5 on the substrate, as shown in Fig. 2 (in Fig. 2, 2 x 2 = 4 shots).

In the second step, while the light-shielding plate is so set as to expose only part of the region, as shown in Fig. 1B, m_2 x n_2 main scale marks (2 x 2 main scale marks in Fig. 1B) are simultaneously transferred (second layer exposure processing). The substrate is moved by a step in the column direction and/or row direction using the moving stage, transferring main scale marks. This processing is repeated to form overlay marks of vernier and main scale marks on the vernier scale marks which are transferred by the first layer exposure processing. That is, p_x x n_2 step movement in the row direction and/or p_y x m_2 step movement in the column direction, and the second layer exposure processing are repeated m_1 x n_1 times, forming overlay marks in m_1 x m_2 rows in the column direction and n_1 x n_2 columns in the row direction, i.e., m_1 x n_1 x m_2 x n_2 overlay marks. In the example of Figs. 1A to 3B, 7 x 9 x 2 x 2 = 252 overlay marks are formed. No developing processing is interposed between the first and second layer exposure processes.

Fig. 3A shows an intermediate state in the second step. Fig. 3B shows four enlarged overlay marks formed

by one exposure. Which of exposure processes in the first and second steps is performed, i.e., which of vernier scale marks and main scale marks are first transferred can be arbitrarily set.

In the third step, the misalignment amounts of N = m_1 x m_2 x n_1 x n_2 formed overlay marks are measured with a microscope.

In the fourth step, values obtained by measuring the overlay marks are substituted into column vectors on the right side in equations 1 to 14 to be described later, and the equations are solved. At this time, a vernier scale mark position error within the shot transferred by the first layer that corresponds to a distortion (which will be described later) can be obtained. In addition, the position error of each shot transferred by the first layer, the position error of each shot transferred by the second layer, and the relative position error of m_2 x n_2 main scale marks transferred by the second layer can be obtained.

In the above-described conventional distortion measurement method (1) (method disclosed in Japanese Patent Publication No. 63-38697), various error amounts are added to a distortion measurement value. In this embodiment, a distortion and various error amounts are separated, and the distortion measurement error can be greatly decreased.

The distortion measurement method according to

the embodiment will be explained in detail by exemplifying $m_1 = 3$, $n_1 = 3$, $m_2 = 2$, and $n_2 = 2$ as a simpler example. Fig. 4A shows a mark pattern example in this case in which 3 x 3 vernier scale marks and 3 x 3 main scale marks are formed. In exposure of the main scale marks, 2 x 2 main scale marks are transferred by a method as shown in Fig. 1B.

As shown in Fig. 4B, the distortion amount of the position of each vernier scale mark 8 in a shot 7 transferred onto a substrate is defined as variables dx_1 and dy_1. Fig. 5 shows shots in the first layer aligned such that two shots are adjacent to each other in the vertical and horizontal directions. Each shot is formed by scanning exposure (step and scan type exposure) or by block exposure (step and repeat type exposure) in which whole shot area is exposed at once. Each shot 9 has errors ex_1, ey_1, and $e\theta_1$ in position and rotation angle that are caused by a stage alignment error. The relative positions between vernier scale marks within each shot are equal.

Fig. 6 shows the definition of the position errors dx_2 and dy_2 of main scale marks 10 which are simultaneously transferred by the second layer. These errors are caused by a reticle manufacturing error, and appear commonly in each shot 11 (Fig. 7) of the second layer. Fig. 7 shows a state after exposure to all shots on the second layer, i.e., a state in which main

scale marks transferred by the second layer overlap vernier scale marks transferred by the first layer.

N overlay marks formed in this way are measured by an automatic reading apparatus (distance between the barycenters of the main scale mark and vernier scale mark is measured). In this example, N = 36 marks shown in Fig. 7 are sequentially read. Letting $\delta_x(n)$ and $\delta_y(n)$ be the read values (barycentric distances) of each mark and n = 1,..., N, $\delta_x(n)$ and $\delta_y(n)$ are given by

$$\delta_x(n) = dx_1(i) - dx_2(j) + ex_1(k) - ex_2(l) - Y_1(i)\theta_1(k) + Y_2(j)\theta_2(l) + \varepsilon_x(n) \quad \ldots(1)$$

$$\delta_y(n) = dy_1(i) - dy_2(j) + ey_1(k) - ey_2(l) + X_1(i)\theta_1(k) - X_2(j)\theta_2(l) + \varepsilon_y(n) \quad \ldots(2)$$

where

$\delta_x(n)$, $\delta_y(n)$: measurement values of the nth overlay mark

$dx_1(i)$, $dy_1(i)$: misalignment amounts of the ith distortion evaluation vernier scale mark

$dx_2(j)$, $dy_2(j)$: misalignment amounts of the jth main measurement mark at four measurement points (m_2 x n_2 points)

$ex_1(k)$, $ey_1(k)$, $\theta_1(k)$: alignment errors of the kth shot on the first layer

$ex_2(l)$, $ey_2(l)$, $\theta_2(l)$: alignment errors of the lth shot on the second layer

$X_1(i)$, $Y_1(i)$: coordinates of the ith mark within a shot on the first layer

$X_2(j)$, $Y_2(j)$: coordinates of the jth mark within a shot on the second layer

$\varepsilon_x(n)$, $\varepsilon_y(n)$: quantization errors by rounding

If $\varepsilon_x(n)$ and $\varepsilon_y(n)$ are negligibly small, unknown variables are $m_1 \times n_1$ $dx_1(i)$, $dy_1(i)$, $ex_2(l)$, $ey_2(l)$, and $\theta_2(l)$, and $m_2 \times n_2$ $dx_2(j)$, $dy_2(j)$, $ex_1(k)$, $\theta_1(k)$, and $ey_1(k)$. The number of unknown variables is $5 \times (m_1 \times n_1 + m_2 \times n_2)$.

The N overlay marks are formed from $m_1 \times n_1$ vernier scale marks i, $m_2 \times n_2$ main scale marks j, $m_2 \times n_2$ first layer exposure shots k, and $m_1 \times n_1$ second layer exposure shots l. The combination of i, j, k, and l for each overlay mark changes between all marks. In other words, equations (1) and (2) are combined into $2 \times (m_1 \times n_1 \times m_2 \times n_2)$ (2N) simultaneous equations.

At this time, if conditions by equations (3) to (14) are added, the simultaneous equations are determined to obtain a solution which minimizes the sum of squares of $\varepsilon_x(n)$ and $\varepsilon_y(n)$.

$$\sum_{j=1}^{m_2 \times n_2} dx_2(j) = 0 \qquad \ldots(3)$$

$$\sum_{j=1}^{m_2 \times n_2} dy_2(j) = 0 \qquad \ldots(4)$$

$$\sum_{k=1}^{m_2 \times n_2} ex_1(k) = 0 \qquad \ldots(5)$$

$$\sum_{k=1}^{m_1 \times n_1} ey_1(k) = 0 \qquad \ldots(6)$$

$$\sum_{k=1}^{m_1 \times n_1} \theta_1(k) = 0 \qquad \ldots(7)$$

$$\sum_{l=1}^{m_1 \times n_1} Y_2(l) ex_2(l) = 0 \quad \ldots(8)$$

$$\sum_{l=1}^{m_1 \times n_1} X_2(l) ey_2(l) = 0 \quad \ldots(9)$$

$$\sum_{l=1}^{m_1 \times n_1} X_2(l) ex_2(l) = 0 \quad \ldots(10)$$

$$\sum_{l=1}^{m_1 \times n_1} Y_2(l) ey_2(l) = 0 \quad \ldots(11)$$

$$\sum_{l=1}^{m_1 \times n_1} ex_2(l) = 0 \quad \ldots(12)$$

$$\sum_{l=1}^{m_1 \times n_1} ey_2(l) = 0 \quad \ldots(13)$$

$$\sum_{l=1}^{m_1 \times n_1} \theta_2(l) = 0 \quad \ldots(14)$$

By solving the simultaneous equations, the stage alignment errors ex_1, ey_1, ex_2, and ey_2, and the reticle manufacturing errors dx_2 and dy_2 can also be obtained at the same time as the distortion evaluation amounts dx_1 and dy_1. No stage alignment error is contained in the distortion evaluation amount.

As described above, according to the embodiment, no stage alignment error is contained in the distortion evaluation amount, unlike the above-described conventional distortion measurement method (1). High-precision distortion measurement can therefore be realized.

In actual distortion measurement, about 100 vernier scale marks are simultaneously transferred for each shot. The number of exposure operations using the second layer is equal to the number of vernier scale

marks within a shot. The number of shots of the first layer is larger by only three (when the number of shots of the first layer is 2 x 2 (four)). The exposure time is almost equal to the exposure time of one shot by the above-described conventional distortion measurement method (1).

An exposure control apparatus which executes the distortion measurement method will be explained. Fig. 12 is a block diagram showing the arrangements of an exposure apparatus, exposure control apparatus, and mark reading apparatus according to the embodiment. Reference numeral 101 denotes an exposure apparatus which comprises an exposure light source 111, illumination optical system 112, light-shielding plate 113, reticle stage 114, projection optical system 115, and wafer stage 116. The reticle stage 114 supports a reticle 121 on which the above-described vernier scale marks and main scale marks are drawn. The wafer stage 116 supports a photosensitive substrate 122.

Reference numeral 130 denotes a control apparatus which controls the exposure apparatus 101 by a CPU 131. The CPU 131 executes various control operations in accordance with a control program stored in a memory 132. Reference numeral 132a denotes a distortion measurement processing program which is executed by the CPU to execute the above-described distortion measurement processing; 132b, an exposure control

correction value which is calculated from a distortion measurement value obtained by distortion measurement processing; and 132c, an exposure job which stores various parameters in exposure processing. While correcting the correction value 132b, the CPU 131 executes exposure processing in accordance with the exposure job 132c, realizing high-precision exposure.

Fig. 13 is a flow chart for explaining processing by the distortion measurement processing program 132a.

In step S101, the light-shielding plate 113 is controlled, and exposure processing using as one shot the entire surface of the reticle 121 having $m_1 \times n_1$ vernier scale marks is repeated $m_2 \times n_2$ times. In step S102, the light-shielding plate 113 is so controlled as to set $m_2 \times n_2$ main scale marks as one shot. Exposure processing using this shot is repeated $m_1 \times n_1$ times, forming $m_1 \times n_1 \times m_2 \times n_2$ (= N) overlay marks.

In step S103, the photosensitive substrate having the overlay marks formed on it is developed using a transport/developing processing system 117. The photosensitive substrate is supplied to a mark reading apparatus 201 to measure the overlay marks, acquiring measurement results ($\delta_x(1)$ to $\delta_x(N)$ and $\delta_y(1)$ to $\delta_y(N)$). In photosensitive substrate developing processing or supply to the mark reading apparatus, another apparatus controlled by another control apparatus may be used manually. In this case,

measurement results are merely acquired from the mark reading apparatus 201 in step S103.

In step S104, the distortion (and stage alignment error and reticle manufacturing error) is calculated by solving the above-described simultaneous equations. In step S105, in executing an exposure job, a correction value for correcting the calculated distortion is calculated and stored in the memory 132.

The light-shielding plate 113 is set on the reticle stage in this example, but may be set within the illumination optical system. In short, the light-shielding plate 113 suffices to realize a function of restricting illumination light so as to set a predetermined number of main scale marks as one shot, as shown in Fig. 1B. This function may be realized by a method other than the light-shielding plate.

A device production method using the above-described exposure apparatus will be explained.

Fig. 14 shows the manufacturing flow of a microdevice (semiconductor chip such as an IC or LSI, a liquid crystal panel, a CCD, a thin-film magnetic head, a micromachine, or the like). In step 1 (circuit design), a semiconductor device circuit is designed. In step 2 (exposure control data creation), exposure control data (exposure job) of the exposure apparatus is created on the basis of the designed circuit pattern. In step 3 (wafer formation), a wafer is

formed using a material such as silicon. In step 4 (wafer process) called a pre-process, an actual circuit is formed on the wafer by lithography using the wafer and the exposure apparatus which has received the prepared exposure control data. At this time, the exposure control data is properly corrected using the correction value 132b, and high-precision exposure processing is executed. Step 5 (assembly) called a post-process is the step of forming a semiconductor chip by using the wafer formed in step 4, and includes an assembly process (dicing and bonding) and packaging process (chip encapsulation). In step 6 (inspection), the semiconductor device manufactured in step 5 undergoes inspections such as an operation confirmation test and durability test. After these steps, the semiconductor device is completed and shipped (step 7).

Fig. 15 shows the detailed flow of the wafer process. In step 11 (oxidation), the wafer surface is oxidized. In step 12 (CVD), an insulating film is formed on the wafer surface. In step 13 (electrode formation), an electrode is formed on the wafer by vapor deposition. In step 14 (ion implantation), ions are implanted in the wafer. In step 15 (resist processing), a photosensitive agent is applied to the wafer. In step 16 (exposure), the above-mentioned exposure apparatus exposes the wafer to a circuit pattern. In step 17 (developing), the exposed wafer is

developed. In step 18 (etching), the resist is etched except the developed resist image. In step 19 (resist removal), an unnecessary resist after etching is removed. These steps are repeated to form multiple circuit patterns on the wafer.

The manufacturing method of the embodiment can manufacture at low cost a high-integration-degree semiconductor device which is difficult to manufacture by the prior art.

As has been described above, the present invention can achieve distortion measurement at a higher precision.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the claims.